

## **Final Report**

**Title: A Communication Framework for Collaborative Defense**

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# **A Communication Framework for Collaborative Defense**

Final Report, PI: K. G. Anagnostakis, Project end date: February 28th, 2008

## **(2) Objectives**

The goal of this project was to explore the potential for a collaborative approach to network defense. The primary focus of this research was in network traffic classification with the intention of supporting advanced policy enforcement capabilities. The technical approach involved a multi-site testbed of live traffic monitoring systems and the design of algorithms for classifying flows to applications, and for generating signatures for previously unclassified clusters of network traffic.

## **(3) Status of effort**

The effort is currently reaching a mature prototype stage with well-tested algorithms, an extensive test traffic archive, over 1,800 applications classified, Gbit/s capable classification, and live trials on 4 sites with more than 40,000 users. Further development is necessary to turn the research artifact into a production-quality system.

## **(4) Abstract**

The goal of this project has been to implement a collaborative automated signature generation system for deep packet inspection systems. In this report we summarize our results at the conclusion of this project. Briefly, the primary goal of achieving a significant level of automation was successfully achieved, although it proved to be more complex than originally perceived. We have been able to provide sufficient automation to be able to build up the most extensive application signature database in the world with a fraction of our competitors resources. Our approach has been tested extensively using real network traffic from internal networks, trial sites, and networks from which we have received confidential network traffic samples.

## **(5) Personnel Supported**

The project supported the efforts of the project team led by Dr. Anagnostakis, and involved research engineers Kirk Jon Khu, Christos Ricudis, and PhD students Saurabh Aurora, and Asia Slowinska.

## **(6) Publications**

The main results of this research are currently in preparation for journal submission. Indirect results from this research (e.g., studies using data produced by the algorithms in this research) are published in the following venues:

- V. T. Lam, S. Antonatos, P. Akritidis, K. G. Anagnostakis, **“Puppetnets: Misusing Web Browsers as a Distributed Attack Infrastructure”**, to appear in ACM Transactions on Information and Systems Security (TISSEC), 2009
- H. Bos, B. Samwel, M. Cristea, K. G. Anagnostakis, **“Safe execution of untrusted applications on embedded network processors”**, in International Journal on Embedded Systems, Vol. 3, No. 4, 2008
- E. Athanasopoulos, A. Makridakis, S. Antonatos, D. Antoniades, S. Ioannidis, K. G. Anagnostakis, and E. P. Markatos. **“Antisocial Networks: Turning a Social Network into a Botnet”**, in Proceedings of the 11th Information Security Conference (ISC’08), September 2008

## **(7) Interactions**

- (a) participation in ISC'08, CSIIRW'08, and visits to UPenn (USA), GMU (USA), and NICT (JP)
- (b) algorithms are further evaluated on real network traffic as part of projects funded by A\*STAR and other public R&D funds.

## **(8) Inventions**

None.

## **(9) Honors/awards**

No honors or awards in reporting period.

## **(10) Archival Documentation**

### **1. Background**

Application fingerprinting and identification from network traffic they generate has always been important for ISPs. Recently, the problem of traffic classification has been attracting a lot of attention due to the popularity of novel P2P applications including content streaming and voice over IP (VoIP). The high network connectivity and traffic imposed by these applications have forced many network operators and ISPs towards application profiling with the intention to control the resource consumption on their networks.

There are at least three factors that make application identification both interesting and challenging. First, as new applications emerge at an ever increasing rate, particularly in the P2P space, coming up with signatures for new types of traffic is increasingly time consuming and becomes a bottleneck as signature development, testing and deployment is usually done manually. Second, applications that are generally regarded as undesirable (and are therefore rate-limited or blocked by operators) are starting to employ encryption and other methods for cloaking their identity. Third, some of these applications often consume huge amounts of bandwidth in unpredictable ways that might interfere with proper congestion-controlled traffic. It is conceivable that a very popular application might even bring the network to congestion collapse regimes.

Currently, fingerprints are developed manually by eyeballing application traces. As new applications emerge, new fingerprints need to be developed, and the process can be quite tedious and time-consuming if performed manually.

### **2. Approach**

The original plan at the beginning of the project was to utilize a preliminary implementation of a signature generator that relies on rabin fingerprints[2] for picking up common subsequences across multiple network flows stored in an offline trace. The resulting algorithm, code-named EAR, was applied on a preliminary dataset and was deemed to be promising. The original goal of the project was therefore to build around that algorithm to support increased automation and the ability to operate on real network traffic.

## 2.1 Interface to DPI engine and support functionality

A prerequisite for this functionality to be implemented is the availability of a suitable DPI engine for application characterization. Although not part of the original proposal or the project deliverables, we have indeed built the necessary engine with the functions needed to support signature generation. These include a) the ability to separate known from unknown traffic, b) the ability to record that unknown traffic for further analysis, c) the ability to operate on both live and offline data through the same interface, d) the ability to test potential signatures for conflicts against other types of traffic.

All these functions are successfully implemented as part of the overall CUB4 engine. Separating known from unknown traffic involved implementing a large part of an actual DPI system. Although there are still many loose ends on this front, the implementation of the core engine is currently mature enough to support live traffic classification at gigabit speeds on commodity hardware.

A special module, called the “dumper” provides the facility for recording traffic to secondary storage for analysis. When a packet arrives from the "raw" channel (through “dumper\_recv”) we check the status of the parent flow to determine what to do with the packet. If the flow is already classified and we are interested in the flow, we need to dump the packet to disk. If other packets of the same flow were buffered pending a decision on this flow, we first have to flush the buffer before writing the current packet. From this point on, packets arriving for this flow do not need to be buffered but are sent straight to either disk or are dropped.

We use two pre-allocated buffer pools for packets of different sizes to hold up incoming packets until a decision has been made. These are organized as linked list for O(1) allocation and freeing of buffers back to the pool. We don't care about sequence at this point (there could be locality issues but it doesn't seem to be affecting us in a big way at the moment).

When a buffer is allocated to hold a packet of a particular flow, we also link it through the internal “flow\_t” data-structure so that we can instantly find the list of buffered packets for that flow as soon as a decision can be made on the flow. As we cannot hold on to packets forever, there is a limit to how much data we'll keep for a flow before having to make a decision. At this moment the default policy is to nudge the detectors to make a decision, by sending them a distress signal, equivalent to a flow timeout/reset. This may affect results in some cases, as without the dumper they would be left alone and could take different decisions.

Special provisions have also been made to filter out flows for which packet loss events have been detected, as such flows can confuse the signature generator. Such problems may occur because the signature generator will try to find good signatures that cover 100% of the traffic, and under moderate loss those parts of the traffic that are lost may contain the otherwise good signature. This functionality is optional, as one may want to try producing signatures that operate well under high load and potential packet loss. A second special provision is the ability to cap the amount of traffic dumped to secondary storage for a particular flow. This is necessary to reduce storage requirements, and it is also sensible as classification has to be completed as early in the lifetime of a flow as possible.

For evaluating new signatures, we have implemented a conflict detection and resolution component, which can handle cases where more than one signatures belonging to different applications match the same flow. In this case, at least one of the two signatures must be wrong, or neither signature is accurate enough to identify only the traffic of the application it is supposed to detect. For all practical

purposes, conflicts are useful for evaluating signature quality and provide useful information for signature fine-tuning.

With this infrastructure in place, it becomes possible to run our engine live on a network, collect all unclassified traffic, and process that traffic in an attempt to find new applications and fingerprint them, or identify flows that belong to existing applications but for which the existing signatures do not perform well.

## 2.1 The EAR algorithm

The EAR algorithm takes a content-sifting approach that extracts protocol fingerprints for specific applications. The tool takes as input a set of candidate packet traces containing traffic generated by the application to analyze, and a set of control traces containing traffic other than the application in question.

The goal of our technique is to determine substrings within a candidate packet trace of a particular application whose existence indicates that a given packet or flow is generated by a particular application. For this purpose, our tool searches the trace for substrings that appear frequently enough to be considered as an application signature. For a given desired length of the signature, and for each packet in the application trace, we consider each substring of the desired length at each position within the packet, and record its occurrence in a cache structure.

### 2.1.1 Basic operation

To efficiently perform this kind of scanning within a packet trace, we rely on Rabin fingerprints. Rabin fingerprints provide a form of a rolling hash of a given size within a stream of larger size. The main idea is to use appropriately selected polynomials so that the rolling hash can be formed as a sum of the value in each position, and with the ability to easily add the next incoming (e.g., rightmost) value and remove the outgoing (e.g., leftmost) value. This can be easily done with prime arithmetic. Rabin fingerprints have been used in similar problems such as content caching, and worm detection. Our own experience, and inspiration to use Rabin fingerprints for generating content signatures, comes from the former domain. However, although in both domains we have based our detectors on the use of Rabin fingerprints, the problem of worm vs. application signature generation differ in many ways.

As application signatures are not of a pre-determined size we use separate fingerprints for each substring length between a minimum and a maximum. For each incoming and outgoing byte we therefore need to update several distinct Rabin fingerprints. The added cost is not a major cause for concern, as the fingerprinting process is performed offline, but it is desirable to not inflate the cost too much. Fortunately, larger signatures can be composed from smaller ones in a post-processing phase, and therefore it is not absolutely necessary to include a large range of substring sizes during basic scanning. At this stage it is only important to pick the minimum size appropriately to avoid overloading the cache on one hand, while on the other hand making sure that good fingerprints make it through to the second phase for signature construction.

Rabin fingerprints are also convenient for supporting offset constraints and providing limited support for regular expressions. An offset-constrained fingerprint is a fingerprint that always occurs at the same offset within a packet or flow. This is expected to be common at least for some network protocols, and is therefore worth giving a try for fingerprinting an application. This allows for more focused signature

generation (e.g., a lower chance of missing the fingerprint during the search due to cache size constraints), operational efficiency (e.g., faster inline search on real traffic), and fewer false positives (e.g., a more well-defined fingerprint is less likely to misclassify traffic of other applications). If no offset-constrained fingerprint is found, then the search can be repeated without this constraint. To support offset constraints all that needs to be done is for the rabin fingerprint value to be supplemented by the offset as the most-significant byte (or byte-pair, for offsets greater than 255) or by otherwise incorporating the offset in the fingerprint value, for example through a XOR operation.

A subset of the regular expression space can also be supported. The basic idea is that we can easily mask out specific bytes from the rabin fingerprint by multiplying out the right factor. Our current implementation uses this idea to support expressions of the form  $\{A?????B\}$  where  $\{A\}$  and  $\{B\}$  are fixed and there is a specific number of ``middle'' bytes considered as variable. Other forms of regular expressions can also be supported; we will discuss this briefly along with second-phase fingerprint post-processing.

### 2.1.2 Signature selection heuristic

The heuristic for selecting fingerprints works as follows. If the substring is seen more than a specified number of times within a flow, and a more than a specified number of times across flows, then it is considered as a *candidate* fingerprint. The idea here is that there may be different forms of fingerprints: some applications may have specific ``magic numbers'' or protocol message identifiers in each packet; other applications may only have an identifying pattern once within each flow; other applications may use separate connections for control and data, or different connections for different types of data. We do not have any insights into whether one form or another is common, or whether one of the above forms is sufficient by itself. The tool should therefore be able to capture all these patterns. One way to do this is by running the tool with different settings. For efficiency purposes, we provide basic support for thresholding on packet and flow counts. Our experience suggests that requiring at least 30 instances of each fingerprint across at least 2 flows works well in most cases. That is, we rely on relatively high sensitivity at this level for selecting candidate signatures. This means, however, that this process will not be able to point by itself to a minimum set of signatures, or a single signature, which would be ideal. Some further processing on the candidate signatures will be required. We will return to post-processing later in this section. An alternative to having a second-phase analysis would be to run the tool with different sensitivity parameters, decreasing sensitivity until we are left with the minimum number of good fingerprints.

### 2.1.3. Cross-trace fingerprinting

We also allow for the use of multiple, independent traces. The idea here is that some applications may have substrings that conform to the above pattern, e.g., appearing frequently enough within and across flows, but some of these substrings may be specific to the trace under consideration, for example, because the local IP address is somehow encoded in a protocol message in a way that makes it a pattern, or because the specific file being transferred between P2P clients is the same across the trace. The use of independent traces is expected to filter out such patterns, as they are not invariant across traces. The additional constraint imposed for this in terms of selecting candidate signatures is that each potential fingerprint needs to appear not just across packets or flows, but also across traces.

Application	Result	Application	Result
PPLive	OK	Azureus	NO 100% FILTERING
PPStream	OK	GreedBT	NO 100% FILTERING
TVAnts	OK	TurboBT	NO 100% FILTERING
TVKoo	OK	Kugoo	NO SIGNATURES
Emule	OK	Shareaza	NO SIGNATURES
BT Vampire	OK	Flashget	NO SIGNATURES
BitSpirit	OK	Joost	NO SIGNATURES
Thunder	OK	Bittorrent-encrypted	NO SIGNATURES
LimeWire	OK	Emule-obfuscated	NO SIGNATURES
Morpheus	OK	FlashBT	missing file
Feidian	OK	WinMX	account needed
CCIP-TV	OK	Bittorrent Plus 2	account needed
QQLive	OK	BitComet	cannot connect to servers
PPMate	NO 100% FILTERING	BT Engine	payment needed
uTorrent	NO 100% FILTERING		

**Figure 1: Evaluation of EAR fingerprinting algorithm on a variety of applications**

#### 2.1.4. Fingerprint cache management

Appropriate design of the fingerprint cache structure is of paramount importance. The tool will have to process large amounts of trace data, in the order of several GB, with each packet generating a number of candidate fingerprints equal to the number of bytes in the packet (minus network-layer headers and the substring length). Each fingerprint needs to be recorded in the cache structure, and to facilitate selection it is necessary to also store additional information such as the flows in which each substring was observed. As we look for patterns across traces, it is also important to record which traces a fingerprint has been identified in.

Our cache structure is designed to be adaptive. We assume that most substrings will not be useful, as they do not appear frequently enough. Thus, new entries should consume a minimum amount of space. Entries that are observed more than a specified number of times will then expand the cache element size to include further information on which flows it was encountered, and instead of statically allocating a certain number of slots for flow information for each fingerprint, we dynamically re-dimension the cache element for this purpose each time we hit the current limit. Eviction is triggered not only when the cache is full, but also when the cache utilization hits a certain level, as we rely on a relatively narrow hash-table and performance degrades as the hash-table becomes heavily populated. Eviction follows a least-recently-used policy, but we also employ *pinning* of ``interesting'' fingerprints -- those that have crossed a first set of thresholds, so that it is guaranteed that they are not accidentally evicted.

Despite being fine-tuned, the cache structure has its limitations, which affect how the tool should be used. The objective is to prevent the cache from getting so full that important fingerprints are somehow replaced and therefore not considered as candidate signatures. Our current experience suggests that it is best for the search to be constrained to the beginning of each flow, for example, the first 4KB. Fortunately, this is consistent with application identification requirements: if the signature user has the intention of using fingerprints to prioritize or drop traffic, then it is important that such action takes place early enough in the flow. On the other hand, users that only care about traffic characterization may not have this constraint, and our tool may occasionally fail to identify signatures that appear in later parts of application flows.

### 2.1.5. Post-processing

After complete scanning of a trace (or set of traces), our tool will have recorded a set of fingerprints of various sizes that have appeared across flows and traces. Due to book-keeping constraints the fingerprints stored in the cache are supplemented only by the number of instances, number of distinct flows, and the flow identifiers up to the point where the signature was put on the candidate signature pile (to avoid increasing memory usage). This is not sufficient by itself to select which among all signatures are sufficient to characterize an application. For example, a fingerprint may be a substring of another, and may seem to appear in the same set of flows. The longer string may be more desirable as it carries equal or less risk of triggering false positives. However, we do not have sufficient information at hand as to whether this fingerprint appeared at some later point in each of the recorded flows compared to the shorter fingerprint. Similarly, seemingly independent fingerprints may occur in the same set of flows, and we would like to remove such redundant signatures. Finally, some signatures may co-exist frequently enough to be considered as a regular expression of the form  $\{A.*B\}$ .

The post-processing phase involves going through the trace once more using a string matching algorithm to match each flow against all candidate signatures. Before going through the trace, we first look at the candidate signatures and try to identify potential larger strings from smaller fingerprints. For example, the first phase may have looked at strings of size 3 up to 10. If the application has a fingerprint of size 30, every 10-byte substring of it must be recorded as a candidate signature. After building this expanded set of signatures, we go through the trace again, and fully record matches for getting a better view of which signatures should be selected. We compute for each signature the number of flows matched, as well as the number of bytes matched (i.e., the size of the flow from the point of match onwards), while building a flow-signature matrix. We also construct classes of signatures that simultaneously match the traffic in the trace for redundancy checks or construction of regular expressions.

As a final step, we start with the signature that has the highest match performance in terms of volume, and mark the flows which are successfully classified by it. We then re-compute the match performance for each other signature on the remaining flows through the flow-signature matrix constructed previously, and continue selecting the highest matching of the remaining signatures until no signatures or no flows are left. In case of signatures that have equal match counts, we chose the longest one with the hope of reducing the risk of false positives.

### 2.1.6. Signature Validation

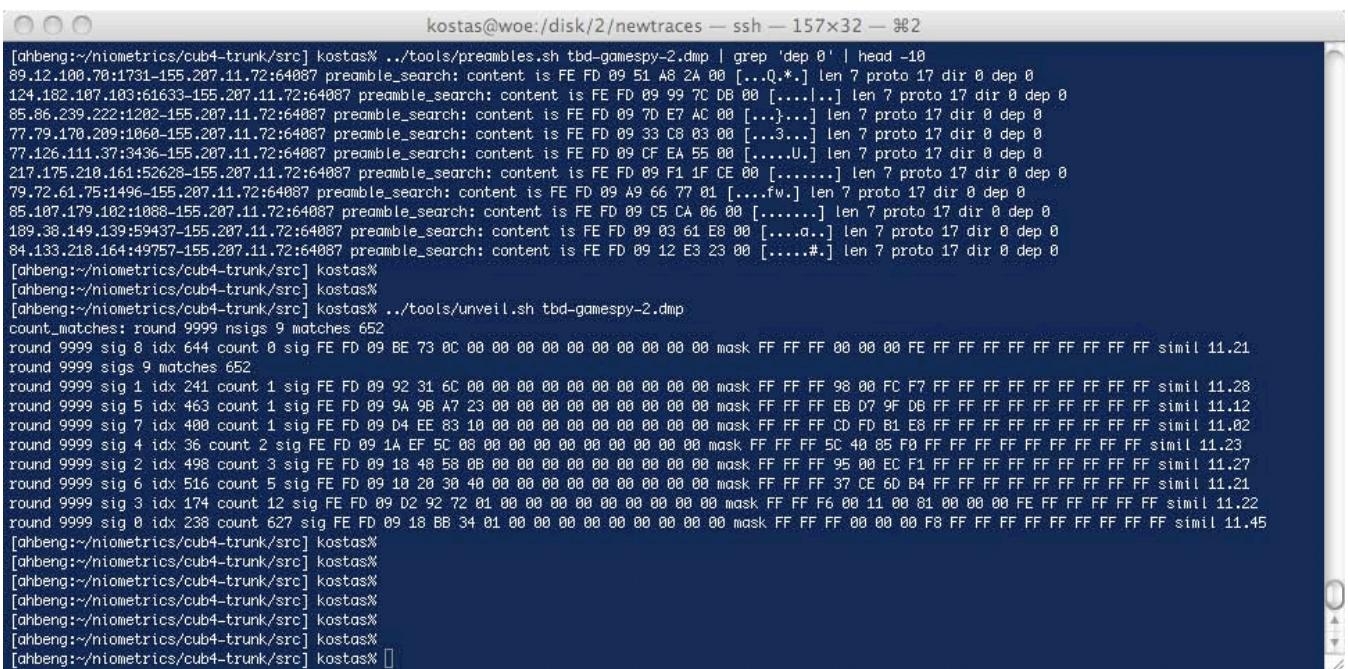
Validating the set of signatures we generated involves two separate questions. The first question is whether the signatures generated match not only the application in question but also traffic from other applications. The common term for such matches is *false positives*. A major concern in testing for false positives is the time it takes to complete signature validation. With this goal in mind we have designed and evaluated an efficient algorithm for signature validation. The approach was originally designed for testing worm signature generators, but has been imported with minor engineering changes for application characterization. In our approach, we incorporate time-space trade-off techniques that are well understood in the context of databases. These techniques allow users to quickly scan for the existence of a key in a database.

To be more specific, we expect from our algorithm a response time much lower than one second. If our algorithm does not use any pre-processing of the captured traffic then only the time required to read the captured traffic from the storage device would be much greater than one second. As a consequence, we have to pre-process the captured traffic in order to minimize the data that our algorithm must read from the storage devices (hard disks). To be more specific our algorithm has two phases, an ``offline'' phase where the captured traffic (trace) is processed and an ``index'' file is created, and an ``online'' phase where the algorithm uses the ``index'' file to validate the signature.

The second question is whether the signatures can characterize application flows, and if employed to block traffic, whether the application can still perform well despite filtering (e.g., through the use of another protocol, or protocol mode, which has not been fingerprinted). The first part of this second question -- whether the signature characterizes application flows, is already answered by the analysis during candidate signature post-processing. The second part of this question requires the user to manually fire up the application with the new signatures installed on a DPI box and determine whether the application still performs well even if the DPI box is instructed to block traffic with the newly-installed signatures.

### 2.1.7. Preliminary Evaluation

We have evaluated our tool by using it to fingerprint 24 applications. Those 24 applications were listed as unclassified for one commonly used DPI platform. The results are summarized in Figure 1. Out of a total of 30 applications that we tried, we managed to work on 24 (the other 6 didn't work at all or required some kind of account, etc.). For 13 out of 24 we were able to obtain and validate signatures. For 7 we got signatures that were not very accurate (e.g., they degraded the application but didn't fully block). For 4 we failed to obtain signatures for various reasons (obfuscation, encryption, ...).



```

kostas@woe:/disk/2/newtraces — ssh — 157x32 — %2
[ahbeng:~/niometrics/cub4-trunk/src] kostas% .../tools/preamble.sh tbd-gamespy-2.dmp | grep 'dep 0' | head -10
89.12.100.70:1731-155.207.11.72:64087 preamble_search: content is FE FD 09 51 A8 2A 00 [...Q.*.] len 7 proto 17 dir 0 dep 0
124.182.187.103:61633-155.207.11.72:64087 preamble_search: content is FE FD 09 99 7C DB 00 [...]!..] len 7 proto 17 dir 0 dep 0
85.86.239.222:1202-155.207.11.72:64087 preamble_search: content is FE FD 09 7D E7 AC 00 [...]...] len 7 proto 17 dir 0 dep 0
77.79.170.209:1060-155.207.11.72:64087 preamble_search: content is FE FD 09 33 C8 00 [...]...3...] len 7 proto 17 dir 0 dep 0
77.126.111.37:8436-155.207.11.72:64087 preamble_search: content is FE FD 09 CF EA 55 00 [...]....U...] len 7 proto 17 dir 0 dep 0
217.175.210.161:52628-155.207.11.72:64087 preamble_search: content is FE FD 09 F1 1F CE 00 [...].....] len 7 proto 17 dir 0 dep 0
79.72.61.75:1496-155.207.11.72:64087 preamble_search: content is FE FD 09 A9 66 77 01 [...]..fw..] len 7 proto 17 dir 0 dep 0
85.187.179.102:1088-155.207.11.72:64087 preamble_search: content is FE FD 09 C5 CA 06 00 [...].....] len 7 proto 17 dir 0 dep 0
189.38.149.139:59437-155.207.11.72:64087 preamble_search: content is FE FD 09 03 61 E8 00 [...]...a..] len 7 proto 17 dir 0 dep 0
84.133.218.164:49757-155.207.11.72:64087 preamble_search: content is FE FD 09 12 E3 23 00 [...]#.] len 7 proto 17 dir 0 dep 0
[ahbeng:~/niometrics/cub4-trunk/src] kostas%
[ahbeng:~/niometrics/cub4-trunk/src] kostas%
[ahbeng:~/niometrics/cub4-trunk/src] kostas% .../tools/unveil.sh tbd-gamespy-2.dmp
count_matches: round 9999 nsigs 9 matches 652
round 9999 sig 8 idx 644 count 0 sig FE FD 09 BE 73 0C 00 00 00 00 00 00 00 mask FF FF FF 00 00 00 FE FF FF FF FF FF FF FF simil 11.21
round 9999 sig 9 matches 652
round 9999 sig 1 idx 241 count 1 sig FE FD 09 92 31 6C 00 00 00 00 00 00 00 00 mask FF FF FF 98 00 FC F7 FF FF FF FF FF FF FF simil 11.28
round 9999 sig 5 idx 463 count 1 sig FE FD 09 9A 9B A7 23 00 00 00 00 00 00 00 mask FF FF FF EB D7 9F DB FF FF FF FF FF simil 11.12
round 9999 sig 7 idx 400 count 1 sig FE FD 09 D4 EE 83 18 00 00 00 00 00 00 00 mask FF FF FF CD FD B1 E8 FF FF FF FF FF simil 11.02
round 9999 sig 4 idx 36 count 2 sig FE FD 09 1A EF 5C 08 00 00 00 00 00 00 00 mask FF FF FF 5C 40 85 F0 FF FF FF FF FF simil 11.23
round 9999 sig 2 idx 498 count 3 sig FE FD 09 18 48 58 0B 00 00 00 00 00 00 00 mask FF FF FF 95 00 EC F1 FF FF FF FF FF simil 11.27
round 9999 sig 6 idx 516 count 5 sig FE FD 09 10 20 30 40 00 00 00 00 00 00 00 mask FF FF FF 37 CE 6D B4 FF FF FF FF simil 11.21
round 9999 sig 3 idx 174 count 12 sig FE FD 09 D2 92 72 01 00 00 00 00 00 00 00 mask FF FF F6 00 11 00 81 00 00 00 FE FF FF simil 11.22
round 9999 sig 0 idx 238 count 627 sig FE FD 09 1B BB 34 01 00 00 00 00 00 00 00 mask FF FF FF 00 00 00 F8 FF FF FF FF simil 11.45
[ahbeng:~/niometrics/cub4-trunk/src] kostas%
[ahbeng:~/niometrics/cub4-trunk/src] kostas%
[ahbeng:~/niometrics/cub4-trunk/src] kostas%
[ahbeng:~/niometrics/cub4-trunk/src] kostas%
[ahbeng:~/niometrics/cub4-trunk/src] kostas%
[ahbeng:~/niometrics/cub4-trunk/src] kostas%
[ahbeng:~/niometrics/cub4-trunk/src] kostas% 
```

**Figure 2: Screenshot of UNVEIL algorithm in action, the top half shows the 10 first preambles encountered in the sample obtained from the AUTH trial site. The bottom half shows the output from the UNVEIL run. The last line of output shows a signature that matches 627 out of 652 samples, while the other proposed signatures have weaker coverage. It is easy for the operator to combine these signatures further.**

There's nothing surprising about the results, but please keep in mind that they are pessimistic. we plan to investigate the 7+4 cases and we might be able to fine tune our signature generator to do better. And,

Short	Full Name	Apps	Active	NIOM	PANT	FACE	SAND	ALOT	EXIN	IPOQ	PKTR	PROC	L7FI	IP2P
P2P	Peer to Peer	240	153	96	30	41	36	46	23	113	18	26	20	11
Streaming	Media/Streaming	312	299	201	57	62	52	37	24	29	26	28	9	0
Messaging	Chat/VOIP	495	369	235	70	283	28	34	11	32	18	14	12	0
Storage	File Sharing-Storage-Backup	302	273	219	43	0	15	2	0	49	1	8	2	0
Business	Business Systems	427	399	284	161	35	11	20	26	5	24	36	10	0
Social	Social Networks	330	232	20	18	303	2	4	3	0	0	3	0	0
Gaming	Games	319	153	111	18	5	18	25	2	3	13	194	9	0
Networking	Networking	362	345	213	143	26	18	22	0	12	0	47	24	0
L3 Protocols	L3 Protocols	1	1	0	1	0	0	0	0	0	0	0	0	0
Other	Unclassified	19	12	12	0	0	0	0	0	0	0	0	0	0
Total		2807	2236	1391	541	755	180	190	89	243	100	356	86	11

Short	Full Name	Apps	Active	NIOM	PANT	FACE	SAND	ALOT	EXIN	IPOQ	PKTR	PROC	L7FI	IP2P
P2P	Peer to Peer	240	153	96	30	41	36	46	23	113	18	26	20	11
N/A	Unclassified	19	12	12	0	0	0	0	0	0	0	0	0	0
Chat	Chat	336	230	176	43	209	17	19	7	12	2	11	7	0
VOIP	VOIP	159	139	59	27	74	11	15	4	20	16	3	5	0
File	File Sharing	176	161	138	21	0	3	1	0	48	0	3	1	0
Backup	Backup	126	112	81	22	0	12	1	0	1	1	5	1	0
Collab	Productivity and Collaboration	91	91	72	50	0	0	0	0	0	1	1	0	0
BizInt	Business Intelligence	11	7	6	1	0	0	0	0	0	0	0	0	0
Conf	Internet Conferencing	96	80	43	14	35	0	0	1	0	0	0	0	0
CRM	CRM	26	21	12	10	0	0	0	1	0	0	0	0	0
Email	Email	66	66	43	40	0	5	7	8	3	8	0	4	0
ERP	ERP	7	5	2	3	0	0	1	2	0	3	0	0	0
Fin	Financial Tools	22	22	20	3	0	0	0	0	0	0	0	0	0
SCM	Source Code Management	8	7	6	5	0	0	0	0	0	0	0	2	0
DB	Database	20	20	12	12	0	0	3	6	0	5	1	0	0
DirAuth	Directory and Authentication	11	11	11	8	0	4	8	8	2	7	3	4	0
AV	Anti-Virus	41	41	35	9	0	1	1	0	0	0	23	0	0
Health	Healthcare	3	3	1	0	0	0	0	0	0	0	0	0	0
Attacks	Attacks	11	11	11	0	0	0	0	0	0	0	0	0	0
Updates	Software Updates	14	14	10	6	0	1	0	0	0	0	8	0	0
Social	Social Networks	330	232	20	18	303	2	4	3	0	0	3	0	0
Gaming	Gaming	319	153	111	18	5	18	25	2	3	13	194	9	0
Total		107	175	167	74	0	0	11	8	5	0	40	15	0

Figure 3: Screenshot of NioDB GUI main screen, showing the application groups and the companies along with the number of applications in each groups that these companies can detect.

of course, for obfuscation and encryption we are trying more advanced approaches, which are outside the scope of this proposal.

## 2.2 The UNVEIL algorithm

Perhaps the biggest deviation compared to the original technical plan is due to the observation that a fairly large number of protocols cannot be characterized by a reasonably large identifying string at a variable offset from the beginning of the packet, which is the focus of the EAR algorithm. In fact, a large fraction of protocols are binary-encoded with just a few fixed fields, as every byte is supposed to carry some meaningful quantity between the communicating peers. For example, the SOCKS protocol uses the first payload byte in the first packet as the magic number (0x04 for SOCKSv4 and 0x05 for

**Dashboard for Application Group Backup**

[Back to main dashboard]

Update | Add Row | Delete Marked |

Delete	Active	Traces	Group	Type	Internal Name	Full Name	URL	NIOM	PANT	FACE	SAND	ALOT	EXIN	IPOQ	PKTR	PROC	L7FI	IP2P	Comm	
<input type="checkbox"/>	-	0	Backup	I	clubbox	clubbox		<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	
<input type="checkbox"/>	-	0	Backup	I	cooldisk	cooldisk		<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	
<input type="checkbox"/>	-	0	Backup	I	dacom	dacom		<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	
<input type="checkbox"/>	-	0	Backup	I	hotdisk	hotdisk		<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	
<input type="checkbox"/>	-	0	Backup	I	neofolder	neofolder		<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	
<input type="checkbox"/>	-	0	Backup	I	netfolder	netfolder		<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	
<input type="checkbox"/>	-	0	Backup	I	pdbo	pdbo		<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	
<input type="checkbox"/>	-	0	Backup	I	popfolder	popfolder		<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	
<input type="checkbox"/>	-	0	Backup	I	totodisk	totodisk		<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	
<input type="checkbox"/>	-	0	Backup	I	wedisk	wedisk		<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	
<input type="checkbox"/>	-	0	Backup	I	VytalVault	VytalVault	http://www.datasurvival.co	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	
<input type="checkbox"/>	yes	-	Backup	I	IBM Tivoli Storage Manager	IBM Tivoli Storage Manager		<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	
<input type="checkbox"/>	yes	-	Backup	I	Veritas NetBackup	Veritas NetBackup		<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	
<input type="checkbox"/>	yes	-	Backup	I	Fast Storage Manager-IBN	Fast Storage Manager-IBN		<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	
<input type="checkbox"/>	yes	-	Backup	I	NFS	NFS		<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	
<input type="checkbox"/>	yes	-	Backup	I	ms-ds-smb	ms-ds-smb		<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	
<input type="checkbox"/>	yes	-	Backup	I	idisk	idisk		<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	
<input type="checkbox"/>	yes	-	Backup	I	Box.Net	Box.Net	http://www.box.net/	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	
<input type="checkbox"/>	yes	-	Backup	I	SWISSVAULT	SWISSVAULT	http://www.swissvault.com	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	
<input type="checkbox"/>	yes	-	Backup	I	Mozy-An EMC Company	Mozy-An EMC Company	https://mozy.com/	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

Delete	Active	Traces	Group	Type	Internal Name	Full Name	URL	NIOM	PANT	FACE	SAND	ALOT	EXIN	IPOQ	PKTR	PROC	L7FI	IP2P	Comm
<input type="checkbox"/>	yes	-	Backup	I	IDrive	IDrive	https://www.idrive.com/	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
<input type="checkbox"/>	yes	-	Backup	I	IBackup	IBackup	http://www.ibackup.com/	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>									
<input type="checkbox"/>	yes	-	Backup	I	Backup-Symantec	Backup-Symantec	http://www.backup.com/	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>									
<input type="checkbox"/>	yes	-	Backup	I	BackJack	BackJack	http://www.backjack.com	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
<input type="checkbox"/>	yes	-	Backup	I	Iron Mountain	Iron Mountain	http://backup.ironmountain.com	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
<input type="checkbox"/>	yes	-	Backup	I	iStorage-Iomega	iStorage-Iomega	http://www2.iomega.com	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
<input type="checkbox"/>	yes	-	Backup	I	Xdrive-AOL Service	Xdrive-AOL Service	http://www.xdrive.com/	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
<input type="checkbox"/>	yes	-	Backup	I	Carbonite	Carbonite	http://carbonite.com/	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>									
<input type="checkbox"/>	yes	-	Backup	I	SOS Online Backup	SOS Online Backup	http://www.sosonlineback.com	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>									
<input type="checkbox"/>	yes	-	Backup	I	Amazon S3	Amazon S3	http://www.amazon.com/	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	partial

**Figure 4: Screenshot of NioDB GUI screen for a specific application group (backup software). We mark as yellow applications which we have not yet investigated. Green are applications that have been fingerprinted already. Red are applications for which we have collected data but for which we have yet to produce fingerprints.**

SOCKSv5), the second byte encodes the requested function to be performed by the other side (for example, 0x01 for opening a connection).

These protocols require a different approach for detection. In our current design, we use “preamble masks” indicating fixed-size strings at the beginning of the payload, with the mask indicating which bytes in those strings are fixed and which ones are variable. For example the preamble mask ‘04013300/FFFF00FF’ matches all packets that start with 0401 and have the 4th byte equal to 0x00 and any value in the 3rd byte. Fortunately, the fact that preambles are matched against a fixed offset in the payload reduces complexity in the matching process, and also makes signature generation somewhat easier.

The goal of the UNVEIL algorithm which we have developed is to take as input a set of traffic samples and produce the minimum set of preambles that covers a large enough fraction of the samples, ideally 100%. The algorithm operates as follows. We consider preambles of a fixed maximum size, which in our current implementation is 16 bytes. We extract, from all flows, the first packet, we take the first 16 bytes with the full mask (FF .. FF), and consider this set of preambles as our initial set of signatures.

The goal becomes to reduce this set to the minimum necessary to fully characterize the application. In each step, we compute the similarity of each preamble to every other preamble in the set.

There can be many similarity measures. The simplest one would be to count the number of identical bits among each pair of preambles, and sum up all the values for each preamble. We use a somewhat more elaborate scheme to introduce some bias in the measurement to favor preambles that have consecutive identical bits. More specifically, we maintain three counters as we compare the preambles: the count of identical bits, the maximum number of contiguous identical bits, and the current sum of contiguous bits across different bytes. The similarity at the end of the comparison is the sum of these three counters.

Once the basic similarity measure has been computed for the set, we find the highest similarity signature in the set and then a second signature where the two signatures can be merged with minimum impact in terms of having to turn off bits in the mask. We could use other measures as well, such as the maximum number of signatures we can eliminate with this approach, but for now we prefer a more conservative strategy and just eliminate one signature at a time, even if this means that the algorithm is going to be slow.

Through several rounds of reductions, up to the number of samples in the initial set, we can derive one or more preamble masks that cover all samples in the initial set. This is the set of candidate signatures, which can often be more than one as preambles cluster around a maximum similarity preamble.

We note that even the first round of computations for similarity is very useful in identifying clusters in the case where the trace has been obtained from the network and may contain several different applications with different preambles. The algorithm is also designed in such a way that we do not require the algorithm to compute a single signature that matches all samples. The end condition is currently set to a maximum of 10,000 rounds of reductions and with some thresholds in each reduction, to avoid overgeneralizing the signatures. A side-effect of being careful in this is that the final proposed signatures may still have obvious generalizations between them, which the operator will then have to merge manually. Although this is far from the ideal of fully automated, unsupervised signature generation, it is still much more efficient than manual eyeballing through large amounts of data, as it reduces the data to a form that can be understood by the operator for the production of signatures within minutes.

### 2.3 Fingerprinting Web-based applications

Another issue we discovered during the course of this project is that an increasing number of applications operate over HTTP and HTTPS. Their traffic would usually be classified as HTTP, and it would not show up as a new blob in our unclassified dumps. We needed ways to identify this kind of traffic, whenever possible, and to have ways to fingerprint it.

There are two primary features that allow such applications to be identified. First, many of them are served in a centralized fashion, meaning that all the traffic would go to specific servers, whose names could be described in signature language. This would typically involve a signature on the Host: or Referer: field.

The second key feature is the User Agent field of the HTTP request. A large fraction of Web based applications use distinct User Agent fields which are very easy to express as signatures. To automate

the extraction of previously unknown User Agent fields we have implemented a specific signature “action” that checks every occurrence of a User Agent field against an updated list of known User Agents. If a new one shows up, it is logged for further analysis. Google and whois can then help identify exactly which application this User Agent corresponds to, if the User Agent string itself is not clear about it.

## **2.4 Application Traffic and Signature Database and GUI**

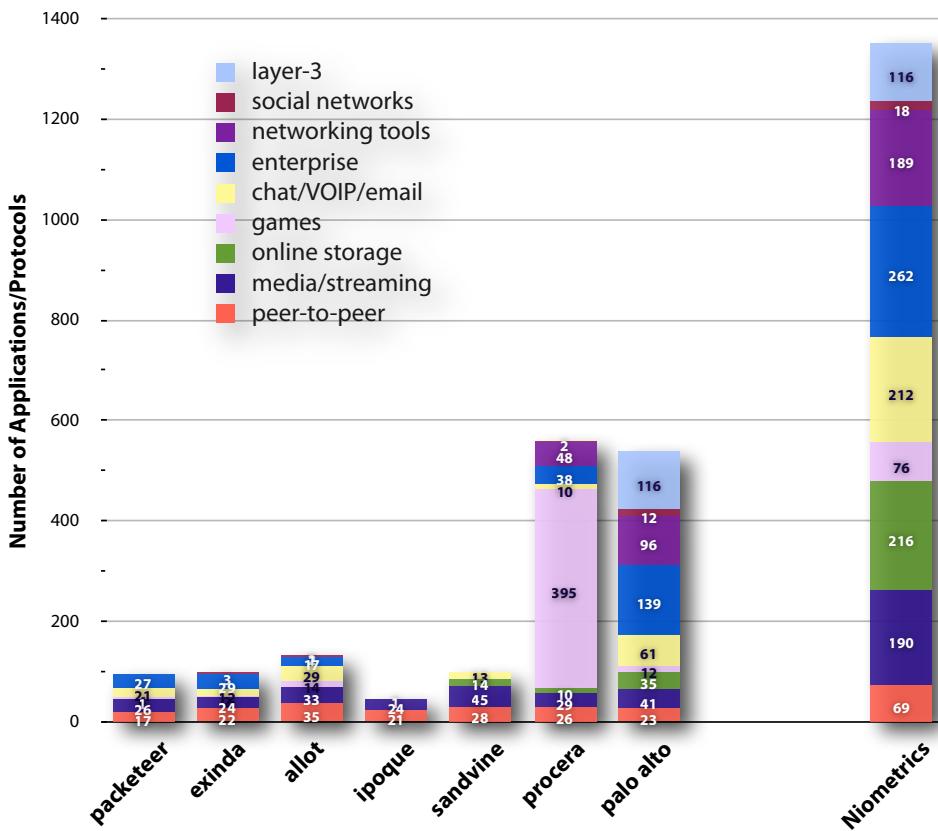
During the course of this project we noticed that quite often we are able to identify signatures from live traffic but without being able to identify which application they cover. In many cases it is sufficient to give them a temporary label until the application’s name is discovered, but this also means that offline data collection cannot be completely eliminated from the signature update process. Combining the two is likely to be more effective, as quite often the temporarily labeled applications will eventually coincide with applications fingerprinted in the lab. Due to the limited number of trial sites and live network data that was available during the course of the project, we put significant effort into collecting traffic samples in the lab, and streamlining the infrastructure needed for this task.

We have developed an extensive database of traffic samples for more than 2000 applications. The names of the applications were obtained through competitors’ application lists, online sites providing information on popular networking software (product review sites such as wakoopa.com, and download.com for example) and information obtained from users and IT managers. The same database also provides us with a comparison of our application coverage compared to competing vendors in the market.

## **2.5 Data Collection Tools**

In addition to the database, we have also ported the CUB4 engine to the Windows XP and Vista platforms, to provide more flexibility and accuracy in data collection compared to simply running windump or wireshark and collecting full traces. A CUB4 wrapper implementing null detection and activating the dumper allows us to capture capped traces that contain sufficient data for analysis at a fraction of the storage needs. At the same time, we have also implemented “FlowProbe”, a module that can tag flows with application data obtained from the operating system. This is necessary as in many cases using a small number of IP addresses for data collection results in significant noise, as stale data in the network, background applications, and random network probes can contaminate the data.

The “FlowProbe” module has an additional feature which is likely to be highly useful in more operational settings. It can broadcast special “hint” packets to the network containing the association of flows to applications. An embedded Niometrics/CUB4 system in the network can intercept these hints and use them to determine if its own classification for each flow is consistent with the “ground truth” as provided by the host operating system. We envision that administrators may ask users with high volumes of unclassified traffic to (temporarily) install FlowProbe so that the Niometrics system can tune itself and learn the previously unknown signature and application.



**Figure 5: Comparison of application coverage between different vendors, including our own project. The resulting coverage is due to the use of our tools on reference traces and a small number of live networks and trial sites.**

#### 4. Insights from trial sites

Up and until November 2008 the project relied almost exclusively on access to I2R's corporate network, and the reference traces collected by our project team. From November 2008 we obtained access to data and trial sites at AUTH (EU), Vivodi Telecom (EU), and an undisclosed university campus (US). The addition of each trial site provided useful insights:

- The data obtained from Vivodi were traces from two datacenters, where the traffic was primarily enterprise applications, LDAP, billing, and backup software. The initial classification rate on this network was relatively low, at around 60%, as several LDAP modes and the backup applications were not included in our database. It took only 1-2 days of analysis to fully cover the applications. Some collaboration was necessary with the network administrators at Vivodi to determine which application was associated with a given set of signatures. Subsequent runs demonstrated classification rates of 99.9%.
- The data obtained from the university campus provided a wealth of new applications, as this is an open network of more than 30,000 staff and students. It took a full week to sift through the data, and we produced new signatures for around 150 applications for which we didn't have any reference data before.
- The AUTH trial site went live on December 18th, 2008. From the early runs we achieved classification rates of more than 98% without any additional signature generation work. Part of the remaining 2% resulted in around 20 new applications being discovered, most of which were related

to Grid Computing, and some which related to botnet activity and SOCKS proxy modes which we had not seen before.

## 5. Caveats and Next Steps

Compared to the ideal of fully automated, unsupervised signature generation, our approach in its current form has some inherent limitations:

- We have observed that sometimes the fingerprints produced by the algorithms are not particularly good. In many cases there are obvious ways to improve them, for example, by further manual reduction. This is not a difficult task, but it means that some supervision is still necessary. Further work is necessary to determine whether it is possible to fine-tune our framework to reduce the need of supervision to a minimum, and to provide more meaningful information to the operator when supervision is unavoidable.
- In some cases the application has a very weak protocol footprint to begin with, and there are no good signatures to discover by any algorithm. This is not just about obfuscated applications -- many other applications that do have a protocol structure don't have a clear enough invariant part that would allow for accurate identification. The operator will have to look for secondary features, such as packet sizes, port numbers, or preambles further down in the packet. In some extreme cases, such as Skype the footprint is so weak that it requires case-specific stateful handling. In other cases, there are known quantities that are embedded in the payload which are variable. For example, some applications encode the message size, which can be easily correlated with the packet size, and other applications encode the source IP, destination IP or transport-level port numbers at specific fields. While it is certainly possible to generalize feature extraction for such cases, it appears that every "difficult" application may still require some degree of unique handling, which the underlying system needs to support.
- Within the scope of an isolated traffic sample, some parts of the payload may seem invariant, when in reality they may change under certain conditions. For example, assume that an application embeds a timestamp in the payload. If some part of this timestamp indicates the year, then it will not be possible to identify the variable portion until a year later. One could then either declare this part to be variable (and mask it out, in the case of preamble signatures) or one could consider that the signature will be changing every year and that this part should be considered invariant for that period of time. It may be possible to adapt the algorithms to detect similarity between unclassified traffic and existing traffic samples, or the existing signatures in the database. An implementation of this would require an appropriate multi-pattern approximate matching algorithm. Given that this will operate mostly offline, there are no stringent performance requirements for this part. This approach cannot be bulletproof, but may in most cases provide a reasonably good guess. Another strategy, which is something that we have been doing manually, is to look at the profile of the flow endpoints. For the internal hosts, we can look back at the applications that we have already identified as running on the host. With some further correlation with other hosts generating similar unclassified traffic, it may be possible to make a better guess as to whether the unclassified traffic belongs to an application we have already identified as running on the host, or whether we should look further for evidence.
- Automating the identification of application name and type is an open issue. Our experience with manual identification suggests that this is difficult without additional access to the end systems, as provided by FlowProbe. In an enterprise setting, this seems reasonable, but in an ISP setting this approach may be too intrusive. Cross-site collaboration may provide some help, but this too seems like a long shot for ISPs.
- The Flash RTMP protocol is a challenge by itself, as it involves a lot of random data at the beginning of the payload, and no clearly identifiable strings until very deep in the payload. As many

applications are nowadays implemented in Flash, it would be important to explore this further. Our current approach here is still somewhat manual.

- Finally, it seems desirable to automate the fingerprinting of non-content features as well. Skype's TCP connections, for example, have a similar feature set to other obfuscated applications, and it looks like there is an opportunity there to automate the extraction of the feature ranges, similar to how we went about extracting the content features.

## References

- [1] Periklis Akritidis, Kostas Anagnostakis, and Evangelos P. Markatos. Efficient content-based fingerprinting of zero-day worms. In Proceedings of the IEEE International Conference on Communications, May 2005.
- [2] Michael O. Rabin (1981) (PDF). *Fingerprinting by Random Polynomials*. Center for Research in Computing Technology, Harvard University. Tech Report TR-CSE-03-01. Retrieved on 2007-03-22.

## Appendix A: List of reference traces

There are 1860 traces in our reference archive. Other traces are also available but are not well organized at the moment and therefore are not “officially” part of this archive.

6422199 Nov 21 17:27 01-mp3search4.0-p2p-install-201108.lavany.pcap  
254894 Oct 22 11:10 123flashchat-chat1-221008-lavany.pcap  
85637 Oct 22 11:11 123flashchat-chat2-221008-lavany.pcap  
108963 Oct 24 10:26 2dvoip-voip-241008-lavany.pcap  
1305123 Oct 24 16:25 2dvoip-voip-install-praveen241008.pcap  
4504942 Aug 28 17:14 2dvoipofficce-crm-praveen.20808.pcap  
4828529 Nov 21 17:13 3big2end-filesharing-install1-praveen.071108.pcap  
6118397 Nov 7 17:06 2big2end-filesharing-webbased-praveen.071108.pcap  
11232311 Oct 25 12:49 3cxvoipclient-voip-install1-praveen.251008.pcap  
6838734 Oct 25 12:39 3cxvoipclient-voip-install-praveen.251008.pcap  
4193838 Dec 2 11:10 3luxe-socialnetworks-web-021208-lavany.pcap  
3627714 Dec 2 11:30 43things-socialnetworks-web-021208-lavany.pcap  
12117098 Aug 11 23:16 4shared-filesharing-install1-praveen.110808.pcap  
4826014 Aug 11 23:07 4shared-filesharing-install-praveen.110808.pcap  
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 9062004 Sep 2 10:06 yandex-email-russian-praveen.020908.pcap  
 8835648 Sep 2 10:00 yandex-email-russian-praveen.020908.pcap  
 1582267 Aug 7 17:38 yodex-networking-praveen.070808.pcap  
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 18844222 Jul 18 14:35 yourfilelink-filesharing-webbased-praveen.071108.pcap  
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 100137809 Sep 7 17:31 yum-softwareupdate-kirk.070908.pcap  
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 3435407 Oct 3 17:12 yuugoo-internetconferencing-praveen.031008.pcap  
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 1025967 Nov 3 16:50 zimpro-chat-091008-lavany.pcap  
 90892 Nov 16:50 zimpro-chat2-301008-lavany.pcap  
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 5723458 Set 1 13:35 zohomail-email-praveen.010908.pcap  
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 4122967 Jul 23 10:01 zoho-notebook-praveen.280708.pcap  
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 3327069 Sep 1 13:11 zohostart-prodcollab-praveen.100908.pcap  
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 4177901 Oct 14:50 zoiper-voip-install-praveen.241008.pcap  
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 1417061 Oct 24 12:02 zoipge-voip2-241008-lavany.pcap  
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 93129128 Jul 25 20:22 zultrax-4.25free-kirk.260708.pcap  
 1881284 Sep 19 12:10 zwiki-businesssystems-productivity-lavany.190908

## Appendix B: List of applications fingerprinted

BitTorrent (Encrypted) 100bao Ants-p2p Aimini AppleJuice Ares AudioGalaxy BitTorrent (plain) DirectConnect eMule (plaintext) eMule (obfuscated) ExoSee FileTopia FlashGet F2F/Alliance F2F/Retrosshare Furthur Gnutella Gnutella Globule Goboogy GrooveShark Hopster Hotline I2P2 iMesh KaZaa/FastTrack Kontiki Manolito Mute Omemo Openfit Pando Joltid/PeerEnabler PerfectDark Poco Share EX/NT Soulseek Thunder (Xunlei) Utatane Vagaa Waste WinMX Winny WinnyP XDCC Zultrax Gazzera Gloster CSpace SouGood Kamun/PFPiLM Maze OFF Freenet Boinc Brunet FileGuri PPMule TuTu P2PIA Orbit WebThunder Kugoo Fileswire PPGOU Napster Kuro chat-av Three Messenger TVCONNECT OPENH323nagios Spark Voice SinaUC SightSpeed Gmail-chat CiscoCTI Windows-POPUP Ventrilo Effusia IM Praize Chikka IMVU Firefly PICCHAT MySpaceIM <a href="http://www.omnik.com/pages/index.jsp">http://www.omnik.com/pages/index.jsp</a> Omnik Potatotalk Buzz IM Wambo NetMeeting/H323 Zfone	Sim-IM POPO ChateX Psi-oppnesource Weblin JBuddy IM Digby Instan-t Tivi Nimbuzz CameraWare Mail.ru-Russian-Video <a href="http://www.theuds.com/instant-messenger.php">http://www.theuds.com/instant-messenger.php</a> DKMessenger IntraMessenger GoogleTalk MessengerFX Miranda-IM FRING xfire TChat Mediating Talk Fetion Inbit AdIRC ParaChat Chat80 basic Pidgin WMS Messenger ZoIPPE ClosedTalk FTP-all DISKpump FTP-Proxy Foldershare Veritas Netbackup NFS ms-ds-smb idisk Deposit Files OnlineFileHosting drop.io DropBoks EatLine FileDropper Mediafire Megaupload Openomy Rapidshare Rapidupload Sendspace WebDAV Yourfilehost Yousendit zShare zUpload Putfile Easy-Share FileFactory FileFront FileHost.tv WiiUpload.net Uploadingit Uploaded to TurboUpload Speedshare.org SimpleUpload ShareBig ShareBee Sendmefile SaveFile Rapidshare.de Megashares Gigasize UltraShare.de Filepouriys File-Upload Files.to Filesend Filer.net Mofile-Chinese FileDen Filegube BigFileZ Angelbackup CrashPlan Egnite Orbit Files-chinese SIP Net2Phone	Xtrek Send6 Sendthisfile Bigfilebox BooMP3 BoxSTR DivShare FilePanda FreefileHosting in.solit.us Mydatabus MyFabrik Supload UpforDown WebCargo WooFiles OVI-Nokia FlyUpload iFolder.ru Imagecave Load to MyFreeig PicturePush Onlinedisk.ru SnapDrive FlipDrive HotLinkFiles Upitus Clip2Net Sendalong Storyz Filevoom ShareNow Go Aruna BigfileHost Reimagine Mongofiles HugeDrive WIXI Uploadjockey Zippshare Rapidspread Adobe-Share FileXom FileWind Filebanker Yourfilelink 2Big2Send HotShare PipeBytes Fileai ShareSend FileWorks SendFile Arkiva KeepSync FreeDrive MediaMaster WikiSend Snaggs Uploaddrive Uschovna-CZ NetGull Z39.50 MSSQL Spread-It Dump.ro MyDrive Box.Net SWISSVAULT Mozy-An EMC Company IDrive iBackup Backup-Symantec BackJack Iron Mountain IStorage-Iomega Xdrive-AOL Service Carbonite SOS Online Backup BackUpSolutions Backblaze Steekup - France Diimo ClunkClick DriveHQ Dacom Webhard Client Korean rsync cvsup MobileMe Wuala-Alpha Jungle Amazon Fluxiom Allmydata	Powerfolder Netmass Putplace DataDepositBox VipBackup Sparebackup WizzDrive Keepit BackupandShare in.solit.us BuddyBackup Intronis Tilana SystemRecovery BingoDisk Firstbackup VaultUSA VeraVault SoSure Sharepoint Blog Posting FC2 Blog Posting-Japanese Apple Remote Desktop Efroom.net-EMC Documentum Facebook Mail Gmail Horde/IMP IMAP (plain, SSL, TLS) Sendalong Storyz Filevoom ShareNow Go Aruna BigfileHost Reimagine Mongofiles HugeDrive WIXI Uploadjockey Zippshare Rapidspread Adobe-Share FileXom FileWind Filebanker Yourfilelink 2Big2Send HotShare PipeBytes Fileai ShareSend FileWorks SendFile Arkiva KeepSync FreeDrive MediaMaster WikiSend Snaggs Uploaddrive Uschovna-CZ NetGull Z39.50 MSSQL InterbankFFX JOKA OptionsDirect SooChowSecurities Z39.50 MSSQL InterbankFFX JOKA BLIN-Spyware ShareNet-VIRUS Slammer-WORM Adobe/Acrobat Apple software update AVG AV update Avast! AV update Avira AV update ShareNet-VIRUS ClamAV update Norman AV update HP Software update Java update Kaspersky AV update McAfee AV update MS Windows Update Microsoft BITS Sophos AV update Elephant Drive File123 MP3unes MyOtherDrive Singtelphononet TalkEZ-AV	Scions of Fate Secondlife Station Launcher-Sony Subspace Tanoth Tibia Tribes Trickster Twelve Sky WarpFire Wolfenstein XX Wyvern XX XBlaster XX Zero Online AsteriskAGI Bearshare7 Cabos0.8 Kceasy Novel NDAP Veritas SANpoint CiscoTFTP CiscoLog CiscoTelnet FingerCisco Citrix Citrix Jedi Consenrtly/log CX300SAN DCC Defendbase Fortinetfw GIOP GoAway GRE HP-printing HTTP Proxy Ident IPP-printing LAN LANadmin Printer Spooler FIN/Worden Games/Minglematch/ Chess DB/SciFinder Games/Sayclub Misc/yapta Misc/DOA/HandleNet Chat/Sparknetworks Games/VinaGames Games/Beyond Chat/Parlringo Games/ArcanaRO Misc/IntelliNetWebcam Misc/CitrixProxy Chat/Starwave Games/DotA Misc/Hope Games/GunzOnline Games/NHN P2P/FreeChalkKR P2P/GetFilm Media/Tivo Misc/Slurpie Misc/JavaMRQ Chat/Groopz Misc/UNICAL Misc/DictD Misc/PNMM Misc/Huntrme Misc/Probes/TracerX Misc/Ruckus/Cache Misc/Rating/ICA FIN/QuoteM P2P/Cubit Misc/OpenDHT Games/minlikewithyou Mionet DragonflyStorm AnarchyOnline Games/XFire utorrent P2P/BitSpirit P2P/BitTorrent/Moopolice P2P/BitTorrent/Deleuge P2P/BitTorrent/ BitTornado P2P/Aquisition P2P/BitTorrent/DNA UPlayMe AIM Digichat OpenIMScore	SLIRP ICMP emulation Apple-Airport AFP (AppleFileServer) Microsoft Routing Server AppleTV TOR (anonymity) Socks SoftEther VNC SSL VmWare X-Font-Server X11 Remote Desktop Bonjour (Cisco) Radius AsteriskAGI Bearshare7 Cabos0.8 Kceasy Novel NDAP Veritas SANpoint CiscoTFTP CiscoLog CiscoTelnet FingerCisco Citrix Citrix Jedi Consenrtly/log CX300SAN DCC Defendbase Fortinetfw GIOP GoAway GRE HP-printing HTTP Proxy Ident IPP-printing LAN LANadmin Printer Spooler FIN/Worden Games/Minglematch/ Chess DB/SciFinder Games/Sayclub Misc/yapta Misc/DOA/HandleNet Chat/Sparknetworks Games/VinaGames Games/Beyond Chat/Parlringo Games/ArcanaRO Misc/IntelliNetWebcam Misc/CitrixProxy Chat/Starwave Games/DotA Misc/Hope Games/GunzOnline Games/NHN P2P/FreeChalkKR P2P/GetFilm Media/Tivo Misc/Slurpie Misc/JavaMRQ Chat/Groopz Misc/UNICAL Misc/DictD Misc/PNMM Misc/Huntrme Misc/Probes/TracerX Misc/Ruckus/Cache Misc/Rating/ICA FIN/QuoteM P2P/Cubit Misc/OpenDHT Games/minlikewithyou Mionet DragonflyStorm AnarchyOnline Games/XFire utorrent P2P/BitSpirit P2P/BitTorrent/Moopolice P2P/BitTorrent/Deleuge P2P/BitTorrent/ BitTornado P2P/Aquisition P2P/BitTorrent/DNA UPlayMe AIM Digichat OpenIMScore	AppServer - NextVIEW AKAMAI-RSP (CDN) Lexmark Printer SUN Storage Tek SUN-NAS RegentDeluxe MarketScore FreeDownloadManager GetRight ICOOLoader DigitalWizard Iria LightningDownload MassDownloader PockeyJP RealDownload Octopus iNetGrabber BigUpload Driveway DropSend JustUp! LocalInstr MailBigFile Condor Replication Service LOCKSS library Oversim Planetlab Ghost replication and backup Panda AV Server Hobbit Logging Altera Quartus Design Sportsline Safebox Xiaonei KyteTV OpenDHT Iminlikewithyou Itiva Kongregate FreeNet6 DNS LDAP Kerberos MSAD rDNS RADIUS SNMP WHOIS Backup- LegattoNetworker acronis Brightstore HSM McAfee SiteAdvisor McAfee Personal Firewall CloudMark Anti-Spam Google Safe Browsing IVMG-Probe NESSUS-Probe helpfixpc-SPAM-MSGR reupdate-SPAM-MSGR Uploading Megashare Transfer Big Files Windows Live SkyDrive 4shared .docstoc Beta Totoexpress - content delivery eSnips Expedat Zoho Share Zoho Viewer EZYFile Jumpcut-Beta Punch Networks Yourfiles.biz Badongo Bitroad.net Skype NetMeeting/H245 Sogou Vovida MSN/Voice STUN eyeBeam JabberSocialHI CiscoLoSGW
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aMSN (filetransfer) Geo Chat Meebo Userplane Shanliao ooVoo ImUNITE Msn2Go Rediff Bol - Indian EyeballChat <a href="http://www.icechat.net/site/">[http://www.icechat.net/site/]</a> IceChat IRC/Normal iTalk VoipBuster Paltalk I)( <a href="http://chatnickle.com/">http://chatnickle.com/</a> Chat-N-Tickle Windows Communicator CamFrog Idefisk-how Zoiper ICQ2Go Zoomcall MSN/Farsight [Nettalk] Brosik Skinny (SCCP) QNext Trillian Stickam Friendvox Me.diumIM Meca Swapper (Wambo) QQ Chatgroups Chatbrowser TokBox imo.im Chatterous DeliciousAnime Instant-e Enterprise Messenger Server LanChat2 TBX Globe7 <a href="http://retroshare.sourceforge.net/">[http://retroshare.sourceforge.net/]</a> P2P Messenger Solegy Chair saw QIP-Russian VyPress Messenger BigAnt-enterprise ICQ <a href="http://www.ispq.com/">[http://www.ispq.com/]</a> iSpQ Click-4-net Phone Mineworldtw mIRC GoogleTalk-Voice Xpanity Spark-IM CommFort IM2 Koolin Loveline Video Personal Adium Pownce Gizmo Peerme X-IM Persistent IM chuPPo <a href="http://www.glnetssoftware.com/m/glchat/">[http://www.glnetssoftware.com/m/glchat/]</a> imhaha FreeVOIP 123 Flash Chat NateOn BYF Chat YahooVoice Mail.ru-Russian Virtual Messenger AIM-express SIP-Open Source test tool <a href="http://ircxpro.com/products/default.asp?product=messenger">[http://ircxpro.com/products/default.asp?product=messenger]</a> IRCXpro Gadu Gadu Bopup IM VZOChat ShoutboxUCOM Cheetah Chat Buddy Spy VoxOx Raketu-IM Facebook Chat ICU2 iCall ActiveWorlds Pantychat Paradise Chat Online Eyejot VooDoo Chat Wipeer Chatango <a href="http://www.gcn.cx/">[http://www.gcn.cx/]</a> GCN Chat 12voip iLoveim Express Talk kzinnovations Talkety MSN Messenger	Alibaba Toolbar Google Earth processing.org OSCPs Dell Network Assistant Yodao Desktop Zino Woori Bank Tencent Traveler Bypassthat (proxy) Asprox (proxy) Avoidr (proxy) Circumventor (proxy) Glype-proxy Megaproxy Jondo (anonymity) Surrogafier (proxy) Phproxy Pingfu (tunnel) Privax (proxy) Zelune (proxy/Web) Vunnel (proxy) SPipe Packetix-VPN Crossloop Desktopto Fastviewer Gotomypc PCanywhere (desktop) Teamviewer (desktop) VNC Xdmcp YOICS Uryte Netviewer Bomgar MyVTO Anyplace Control TechniLine Kproxys LWAPP (wireless) Zmaap (config) Altiris-Symantec ESRO CanonBJNP Folding at Home Hawking NCSI APT MS Virtual Earth Live Search Mobile TPTEST MikroTik Router probe APC UPS sw Dealio Toolbar MSN Mobile Services Postit MS-SQM Skinkers LinkedIn Orkut Naymz Facebook hi5 Webshots Stumbleupon Livejournal Friendster WAYN Xobni MSN Spaces Bebo Plaxo iTimes-Indian Woopyh Yammer AVI Babelgum CSAM CDDB CyberlinkLIVE iTunes EasyTV Flash Video Feidian Joost (encrypted) Kankan LiveStation LastFM MMS MIRO mcastIPTV MinisAP Mercora OctoShape ORB OGG PPStream PPFile PPMate Quicktime QTRAX QQlive RayV RealMedia RTMP RTSP RTP SopCast Zoho-IM TryFast Messenger DBabble Chat PortaOne Yandex.ru FlashComs	stashbox.org MyDocsOnline Nakido Syncplicity Cuckoo Adrive Zogmo SpiderOak SugarSync <a href="http://www.memo.com/download.html">[http://www.memo.com/download.html]</a> Omemo Memopal ExaVault GlobalDrive Computerstorageservices Storegate Youku Klikvu Crunchyroll Flizq Revver blip.tv xm-radio Live365-audio Pandora TV Pandora (radio) Ruckus Viddler TVZone MyVideo-German 56-Chinese Pomocho-Chinese 6 Rooms-Chinese-youtube Rox-online video and TV ChinaonTV-24/7 FREETUBE-online TV/Cable Channel Mogulosis-Live Broadcast DaumTV-PotPlayer Vimeo-Video Sharing For you Ustream.TV GUBA Nifty TV-USA Miro-Internet TV Video Player Neokast Hulu-US Meabox-chinese MeeVee Metacafe Move Networks Sociality Vakaka MeeMix WuaLa Gameplay/VShare StreamerOne NinjaVideo Cortado TVMAO Qik eMusic GOM TV Google Video Netflix SoapBox (msn video?) Totorosa JJAM Creative Zencast Banshee Brightcove DCS2120 - Net Camera Radio Virgin Radio Raketu.tv MSNBC TV DangerRadio Play Music Videos Rykodisc Oyoyala-Backlot FoxNEWS Limelight Networks iriver plus VideoRaptor BlinkX ChannelChooser Channel King Invite iTV LinkTV The Internet TV Software TV-Video wiiTV Sohu GoFish Clipser Ku6-Chinese LiveVideo Trilulu-Romanian Crackle LiveLeak Songbeat Tagoo.ru	ybari AV update PatchLink update Antigen update Fujitsu NAVI update iPhone App Tap updater Logitech update F-Secure AV update ZoneAlarm Symantec AV update Trendmicro updaters Rogue Remover Update ZOHOShow ZOHOWriter ZOHONotebook ZOHOSheet ZOHOMEeting ZOHOWiki Groove (MS) jetspot-editing now google sites mediawiki-editing moinmoin-editing socialtext-editing tikiwiki-editing editgrid Google-calendar Google-docs Meeting Maker thinkfree Writeboard Webex-weboffice Sina-Chinese RTube OUOU MyVideo-German TVZone Photobucket-Video 56-Chinese Pomocho-Chinese 6 Rooms-Chinese-youtube Rox-online video and TV ChinaonTV-24/7 FREETUBE-online TV/Cable Channel Mogulosis-Live Broadcast DaumTV-PotPlayer Vimeo-Video Sharing For you Ustream.TV GUBA Nifty TV-USA Miro-Internet TV Video Player Neokast Hulu-US Meabox-chinese MeeVee Metacafe Move Networks Sociality Vakaka MeeMix WuaLa Gameplay/VShare StreamerOne NinjaVideo Cortado TVMAO Qik eMusic GOM TV Google Video Netflix SoapBox (msn video?) Totorosa JJAM Creative Zencast Banshee Brightcove DCS2120 - Net Camera Radio Virgin Radio Raketu.tv MSNBC TV DangerRadio Play Music Videos Rykodisc Oyoyala-Backlot FoxNEWS Limelight Networks iriver plus VideoRaptor BlinkX ChannelChooser Channel King Invite iTV LinkTV The Internet TV Software TV-Video wiiTV Sohu GoFish Clipser Ku6-Chinese LiveVideo Trilulu-Romanian Crackle LiveLeak Songbeat Tagoo.ru	P2P/Blubster P2P/FileZilla P2P/LimeWire BlogTV FIBS Peekshows FinalFantasyXI BarnesNoble FIS Armygame ETrade Fix FootballNFL WorldWinner Left4Dead Logitech F-Secure ZoneAlarm Symantec TrendMicroURLFilter Centpoker FortinetWL BlackPlanet ATTRelayCall CingularExpress CodianMCU WindowsCommunicator or ProphetCharts MSAirSync NETBIOS-SSN inSpeakCommunicator LANTalkNet MeBeam MSNzone Bakbone/NetVault P2P/DKS Orkut/Dicegame Span/Cutwall Weblogic Hi5Chat Elchat Legal/Westlaw OpenVPN KTorrent Transmission µTorrent Emule xtreme Mod BitComet Tudou Mediabolic UrbanTerror onferencing-Liveoffice iVocalize VOXWire InstantPresenter Netsis Livetook Yuuguu Oneeko BrainShark Wikispaces Pbwiki Spread Persony CloudMeeting CentricCRM Etelos-CRM opencrx-CRM salesforce SUGARCRM Tustena vtiger ZOHOCRM iZeno Netsuite 24SevenOffice Highrise Aim-mail Hotmail FoxSuite ContactOffice ConceptShare GroupLoop Business IT Online Task Manager Buzzword-Adobe Beta HyperOffice ContactOffice ConceptShare GroupLoop Business IT Online Stixy Gilde OS Bloomberg WebAssist GetIt Done - Exvo InformationBuilders- WebFOCUS SAS TIBCO-Spotfire (!)QlikView JasperSoft Adobe Connect Pro Campfire Elluminate Gotomeeting-Citrix netspoke-now premier global Octopus Vview WebEx-cisco Yugma Blackboard-Education GraphOn JIRA Studio FileMaker MySQL POSTgreSQL TACACS AVG Arcavir Ashampoo AntiVirus BuddyBuddy TeamSpeak BCCITV-Cricket	WebThief DownloadAccelerator DC-Sakura DDemon DDruid DownloadExpress DownloadMaster DownloadNinja DownloadWonder SiteSucker SmartDownload SpeeditDownload Webscanner URLGetFile NetAnts NitroDownloader WebPix WebDownloaderX YanaSoft/WebAuto WildsoftSurfer WebStripper wxDownload WWwoffile NicksoftWinGet News/NTP SUN/JavaAppServer Mobile/MMS Google Toolbar ttlenet Blokus Counterstrike GameSpy GarenaGG MSNzone Bakbone/NetVault P2P/DKS Orkut/Dicegame Span/Cutwall Weblogic Hi5Chat Elchat Legal/Westlaw OpenVPN KTorrent Transmission µTorrent Emule xtreme Mod BitComet Angels Online Asherons Call Bridgebase Bomberclone BOTS lobby+login +updater Dance! DarkEden Darkorbit Decide Online Dofus DrakkarZone EverQuest Eate Fiesta FreeCiv Furcadia Globulation 2 Gunbound Gunz Holc Hero Online IAHNET/G Ikariam LineAge II Luminary MixMaster MSN Zone MU Online MythWar Navy Field update Neocron 2 Nexuiz Party-Poker Poker Stars Pogo PostalServer Rakion Red Stone Rubies of Eventide RuneScape Azureus/Vuze Location/AIVDM ahoo video Abacast AOL streaming CCIP-TV CNN streaming NetShow Podcast eMill ORACLE SAP MetaTrader-FOREX Forex Capital Markets FxPro vCapFutures Saxo Trader ePeachtree SCM/CVS SCM/Git SCM/Perforce SCM/Subversion SCM/Mercurial HelixDNA Muvee Xbox Media Center GomPlayer IndiaLiveTV ErosEntertainment- Indian Atom Wuapi Age of Conan IAx FreeTV Phulk-i-Indian
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## **Appendix C: Sample of signatures generated**

## **(11) Software and Hardware**

Not foreseen as part of the project deliverables.